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RELATIONS BETWEEN SHIP DESIGN AND SEAPLANE DESIGN

By Georg Schnadel

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RELATIONS BETWEEN SHIP DESIGN AND SEAPLANE DESIGN*

By Georg Schnadel

Seaplanes, because of their speed, seem especially adapted to supplement traffic by ship. However, they have hitherto been lacking, to a considerable extent in safety, economy, and range. Especially must their seaworthiness be improved, since forced landings on the water cannot be avoided, and without seaworthiness, frequent total losses must be expected. Consequently, high insurance premiums and a lack of freight and passengers are to be expected. Our comparisons will accordingly be limited to large seaplanes of at least ten metric tons (22,046 lb.) flying weight.

The seaplane should be designed as a pronounced long-distance aircraft with a large aspect ratio of the wings and a minimum drag. The propeller efficiency should be as great as possible and the fuel consumption per kilometer (or mile) as small as possible.**

Such a seaplane should also have satisfactory stability and seaworthiness on the water, water-tight bulkheads, fire protection, adequate strength in a seaway and adequate life-saving and radio equipment. It should be clearly understood, however, that safety is only relative and that there is no absolute safety.

*"Zusammenhänge zwischen Schiffbau und Seeflugzeugbau." Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 14, 1931, pp. 453-456.

**Hoff: "Das Grossflugboot," a paper read before the Ges. der Freunde und Förd. der Hamb. Schiffbau-Vers.-Anstalt, 1927, Werft-Reederei-Hafen, Vol. VIII, 1927, pp. 504-516.

Kussner: "Das wirtschaftliche Ozeanflugzeug." Zeitschrift für Flugtechnik und Motorluftschiffahrt, Vol. XIX, 1928, pp. 513-530.

I. Stability

Stability means the ability of a floating body to right itself after a disturbance of its equilibrium. The static stability of a floating body is measured by the restoring moment. This has two components: stability of form and stability of weight. For small inclinations, we have the formula

$$M_{st} = W\ BM \sin\phi \pm W\ BG \sin\phi = W\ GM \sin\phi$$

BG being the distance between the centers of gravity and buoyancy, W the weight, and GM the metacentric height. (Fig. 1.)

In seaplanes BG is generally very large, so that the negative sign applies. Hence it is generally very difficult to secure adequate stability in a seaplane with only a central hull. Twin floats or some other means of adding stability such as sponsons or side floats must be used, in order to produce an additional restoring moment.

Figure 2 shows the relative stabilities for a certain draft.* The rolling moment of the wind pressure on a wing is also shown. In every case there seems to be adequate stability and safety against capsizing. It must be remembered, however, that long-distance airplanes require a very heavy fuel load, amounting to about 40% of the take-off load. Stabilizers should therefore be effective for a wide range of drafts. They must accordingly have a considerable depth, as their efficacy is destroyed when they are submerged.

It is possible to make a twin-float seaplane with satisfactory stability, but the freeboard must be high enough, so that it will not nose under when starting in a seaway. The disadvantage of this arrangement lies in the weight and high cost of the two floats. The resistance in both air and water is also greater than for other types. (Fig. 3.) These factors have greatly hindered the development of large seaworthy twin-float seaplanes. Because of these disadvantages, twin floats are not suitable for long-distance seaplanes. On the other hand,

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*Garner and Coombes: "Seaplane Hulls and Floats." Aircraft Engineering, London, Vol. II, 1930, pp. 193-223.

twin floats are always preferred on small seaplanes for reasons of stability and seaworthiness.

These disadvantages pertain in a still higher degree to seaplanes with more than two floats. Such seaplanes have poor seagoing characteristics and impaired strength for taking off and landing in a seaway.

The flying boat with wing stubs is especially simple and economical. There is one considerable difficulty, however, if the stability is to be maintained at different drafts. Since the height of the stubs is limited, the stability varies greatly at different drafts. For stability in taxying and in taking off, they require a rather large angle of attack (fig. 4), which causes great resistance both on the water and in the air.* Moreover, the boat is endangered by the waves in taking off and in landing, since the force of the impacts increases as the cube of the linear dimensions. The requisite strength is very difficultly attainable, even for flying boats of very large dimensions. Hence this type of seaplane is not suitable for long flights.

Outside of Germany, airplanes with supporting floats are preferred. Recently such supporting floats have been placed near the hull, with the retention of the wing-tip floats on biplanes. Notwithstanding their slight resistance to air and water, wing-tip floats should not be used on seaworthy flying boats. The boats are tossed about violently, and the delicate wing tips are liable to be damaged. Hence wing-tip floats are not desirable on monoplanes.** Inboard floats are best, therefore, for seaworthy seaplanes. Their resistance can be greatly reduced by giving them the proper form.

In view of the rolling moment produced by the wind pressure and the requisite large aspect ratio of the wings, seaplanes should have tapering wings with high wing loading. (Fig. 5.) Protection of the wing tip when rolling and a favorable - not too high - position of the center of

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*Garner: "Seaplane Hulls and Floats." Aircraft Eng., 1930.

Gouge: "The Design of Seaplanes." Aircraft Eng., 1930, p. 202.

Rennie: "The Development of Long-Range Flying Boats." Aeronautical Engineering, 1931.

**Brandt: "Englischer und deutscher Flugbootbau," Luftwacht, 1929.

gravity can be obtained by using a large dihedral angle. (Fig. 6.)

By using these ideas regarding their construction, it seems possible to build large stable flying boats of 50 metric tons (110,231 lb.) without auxiliary floats. The hull must then be made broader above the step.

Because of the air resistance, angular ship-shaped forms of hulls and floats above the water line should be avoided. British experiments indicate that their tops should be well rounded. (Figs. 1, 6, & 7.) The drag is thus reduced about 20%, disregarding the interference drag due to the obstruction of the circulation about the wings.*

2. Propulsion

In designing ships, great importance is accorded the safety of the power plant. On freight steamers, it is completely separated from the rest of the ship by bulkheads and shaft tunnels. The power plants on seaplanes must be correspondingly well protected. The best way seems to consist in giving the engine and propeller an elevated position. It is hardly possible to give a high position to the propeller alone, due to the heavy and complicated driving gear which would thus be necessitated.

In seaplane design, it is difficult to locate the radiator in the propeller slipstream, where it must be placed, in order to have sufficient cooling effect while taxying. Frontal radiators are known to have a very high resistance. If the radiator is suspended directly before or behind the propeller, the efficiency of the propeller is greatly reduced. It is therefore desirable to install the radiator at a sufficient distance from the propeller. In the case of a pusher propeller, the loss is then partially recoverable. It is also possible to use radiators of the British type, with which a down-flow of the propeller slipstream is possible. Likewise, surface radiators, in the leading edge of the wing or on the engine support, are desirable.

Another important improvement consists in the introduction of the Junkers heavy-oil engine with its low fuel consumption. Despite the greater weight of the engine,

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*Mitchel: "Racing Seaplanes and Their Influence on Design." Aeronautical Engineering (Aeroplane), 1929.

it considerably increases the range of long-distance airplanes, as likewise the economy of operation.

3. Water-Tight Bulkheads

Water-tight compartments greatly increase the safety of seaplanes. This point has recently received much attention from ship designers and has been the main theme of international conferences.

The requisite degree of protection by water-tight subdivisions for passenger ships is determined by the length and speed of the ship and the number of passengers. The distribution of the water-tight compartments will also depend on the liability of the different parts of the ship to injury.* For seaplanes the speed can have no influence on the requisite degree of safety, but the size of the seaplane and the number of passengers must be considered. One water-tight compartment is sufficient for a small seaplane and two for a large seaplane, i.e., one or two compartments may spring aleak without danger of the craft sinking. In seaplanes, the portion near the step is especially liable to injury from take-off and landing impacts. Even in middlesized seaplanes this portion should be so divided that two compartments can be flooded without danger of sinking. Very large seaplanes may have a double bottom in the vicinity of the step. Moreover, provision must be made for preserving the stability of the seaplane, in the event of the flooding of one compartment in the hull or stabilizing floats, and by wing tanks in case two compartments are flooded. Openings in the bulkheads should be closed by sliding doors, because hinged doors are not safe enough. It should be possible to close the bulkhead doors from either side or from above.

4. Protection against Fire

Easily inflammable fuels, like gasoline, should be stored outside the fuselage, as on submarines, the wing being well adapted to this purpose. Fresh air must circulate on all sides of the tanks.

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*Laas: "Die Schwimmfähigkeit der Fahrgastschiffe," S.T.G. 1929.
Konigs: "Der Internationale Vertrag zum Schultz des menschlichen Lebens auf See," S.T.G. 1930.

5. Construction

The ratio of the frame spacing to the plate thickness ranges:

in ships, from	30:1	to	80:1
" seaplanes, from	200:1	"	800:1.

Ships are built with plates which resist shear and compression; aircraft with a thin skin. Whereas the ship designer strives to prevent buckling under normal stresses, the aircraft designer uses constructions with corrugations in the skin. Hence such constructional features as lightening holes in the webs should not be used by ship designers.

Hulls and floats are now made entirely of metal, though the more economical wood construction is still successfully employed. The chief advantage of metal construction is the facility of producing very smooth surfaces, thus diminishing the resistance. A beginning has recently been made in England in the use of rustproof steel in place of light alloys, for surfaces below the water, in order to avoid corrosion.

Increases in size have hitherto been made without regard to economy or risk. Under the pressure of economy no further increase in size is to be expected, but rather a decrease. I think it is better to develop the long-distance seaplane first and then undertake to increase its dimensions. The Rohrbach Romar, built for the French, is capable of making a nonstop flight of about 3500 km (2175 miles) with a useful load of 800 kg (1764 lb.), a total starting weight of 19,700 kg (43,431 lb.) and a fuel consumption of 7200 kg (15,873 lb.) at a cruising speed of 160 km (about 100 miles) per hour.

According to British experiments, the resistance is considerably reduced by rounding the hull and floats. The resistance and propeller efficiency seem to be capable of further improvement by improving the radiator, and a saving in weight seems to be possible by bracing the wing.

Under these conditions a considerable increase in flight range and speed may be expected. The flight range can be increased to about 5000 km (3100 mi.) simply by using the Junkers oil engine.

In conclusion I wish to call attention to the fact that British flying-boat designers have recently expressed views which are in part similar to those here enunciated. Seaowrthy long-distance seaplanes require the monoplane type of construction with high wing and tail and protection of the power plant from the waves. The stability of the hull must be insured by floats. It is believed that the resistance of such a flying boat is less than that of a landplane.

This is the trend of the most recent products of the Blackburn Aeroplane and Motor Co., Ltd.*, Saunders Roe,** and the Supermarine Aviation Works.***

While the first two companies have already completed flying boats of the new type, the Supermarine Aviation Works has recently received from the very conservative British Air Ministry an order for the construction of a large flying boat with a span of 53 m (about 174 ft.), an engine power of 5400 hp, and a speed of 235 km (146 mi.) per hour.

Discussion

Mr. Croseck: In shipbuilding it is generally sufficient to consider only the static stability. The differences in shape and structure are slight. The static-stability moments will differ but slightly from one another for the same initial stability. The inertia forces will also be of the same order of magnitude.

In seaplane construction, the shape and arrangement of the flotation gear vary greatly. The static-stability moments may differ greatly for the same displacement and initial stability. Considerable variations in the inertia moments can be effected by varying the arrangement of the flotation gear, airfoils and power plant. As a criterion for the requisite stability, however, there is the fact that large inclinations in forced oscillations in the seaway must be avoided.

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*Cf.: "A British Reconnaissance Boat." Aircraft Eng., 1930, p. 201.

**Cf.: "A Flying Boat Series." Aircraft Eng., 1930, p. 199.

***Cf.: "Aeronautics in 1930." The Engineer, Jan., 1931.

Synchronism between the wave period and the natural rolling period is dangerous. In shipbuilding, therefore, it is endeavored to keep the inertia radius large and the metacentric height small. This produces long rolling periods with respect to the wave period. The inertia radius is limited in seaplane construction. This leads to large metacentric heights. The natural period of roll is very short. The motions are similar to those of a raft.

The flotation gear, hitherto tested and shaped only for taking off and landing, should also be tested for taxying, rolling, and lying at anchor.

Dr. Bader: From the viewpoint presented by Professor Schnadel, it is not easy to understand why seaplanes should be made with wing stubs. It is hardly necessary to mention here that, from the purely aerodynamic viewpoint, the inboard float offers less resistance, due to its longer lever arm corresponding to the smaller buoyancy required for producing the same stabilizing moment. In this connection, however, attention should be called to the fact that, with inboard floats, the stabilizing moment must be transmitted through a much longer distance to the hull, which necessitates a considerable weight increase for a given degree of strength. Consequently, the structure is not so strong as is possible with stubs with their broad bases applied directly to the hull, and the supporting floats might accidentally be torn off. Inboard floats are also more liable to nose under in a seaway than stubs located at the right height and set at the right angle. The aerodynamic disadvantage of a large angle of setting for the stubs, as claimed by the lecturer is, in fact, not upheld by tests. Moreover, the stability under different loads varies but slightly and at the greatest angles of heel at which the wing touches the water, is practically the same.

Sliding doors for the bulkheads, as in a ship, seem inexpedient for the weaker hulls of seaplanes. Hinged doors can be made to shut more tightly.

Dr. Grulich: With the development of more reliable long-distance seaplanes, their seaworthiness becomes less important. Constructors should endeavor to make seaplanes so reliable in flight that forced landings will not occur. Especially in large seaplanes, such as will be necessary in future for transoceanic flight, this can be attained by making the wing structure and the power plant sufficiently

strong and by providing enough reserve power so that the seaplane can fly with one or more engines stopped. Furthermore the engines can be mounted in the wing so as to be accessible in flight.

The propellers can be protected from spray by being located near the trailing edge of the wing. A lower degree of seaworthiness will then suffice.

Dr. Carl Töpfer: I am especially interested in the statement of Professor Schnadel regarding the increase in the apparent resistance of the complete seaplane as compared with the sum of the resistances of the separate parts. To what angle of attack does the stated value of 40% correspond? It is only apparent resistance, because it is really additional "induced drag" due to the disturbance of the elliptical lift distribution. In order to establish this, the relation of the angle of attack would have to be known. Additional induced drag is important for seaplanes, because it has the greatest effect on the take-off and landing ability at low speed, i.e., at large angles of attack. The disturbance of the elliptical lift distribution by fuselage, hull and floats must therefore receive particular attention in the designing of seaplanes.

Professor Schnadel (concluding remarks): Regarding the comments of Mr. Crosock, I would only remark that the stability of a ship may vary greatly according to whether it is traveling in ballast or fully loaded. Ships with a low freeboard should always be investigated for dynamic stability. The periods of roll differ greatly according to the size of the ship and the state of loading.

To Dr. Bader I would say that the weight increase due to the use of inboard floats is small, because the wing spars are already large so as to withstand the aerodynamic forces. The landing impact on the floats can be greatly reduced by shaping their bottoms correctly, so that there need be no fear of damage. If rightly formed, there is no danger of nosing under in a seaway.

My statements regarding the air resistance of wing stubs are indirectly confirmed in Dr. Dornier's lectures, in which the considerable lift is mentioned. The unfavorable aspect ratio, however, results in a rather large induced drag.

I agree with Dr. Grulich that the flight characteristics of seaplanes should first be improved and that the seaworthiness should then be made as great as possible.

In reply to Dr. Töpfer, I would say that the total drag of the seaplane was 14% (not 40%) greater than the sum of the drags of the separate parts.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

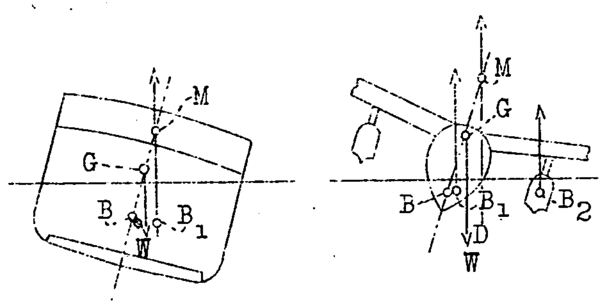


Fig.1 Ship and seaplane stability.

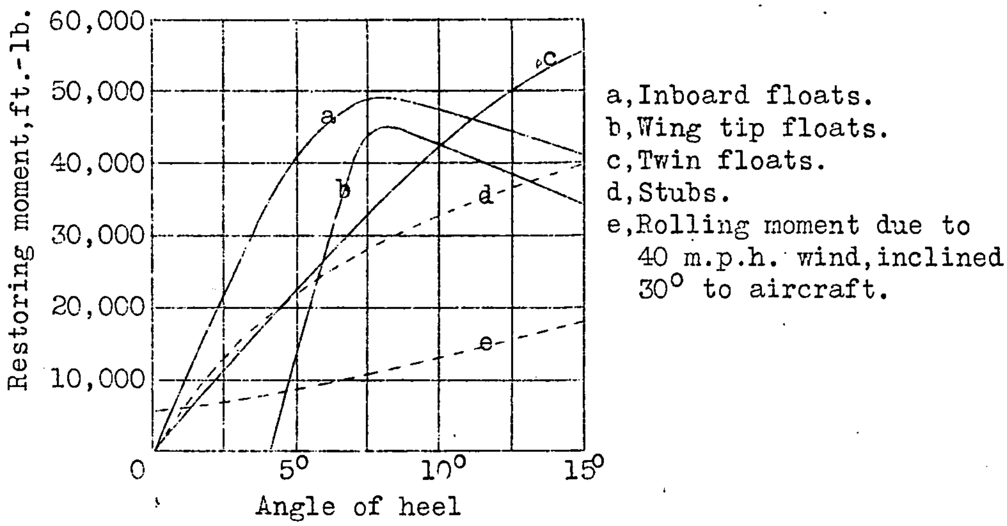


Fig.2 Comparitive lateral stability of a twin engined flying boat, with various types of stabilizers. Weight, 14,300 lb.

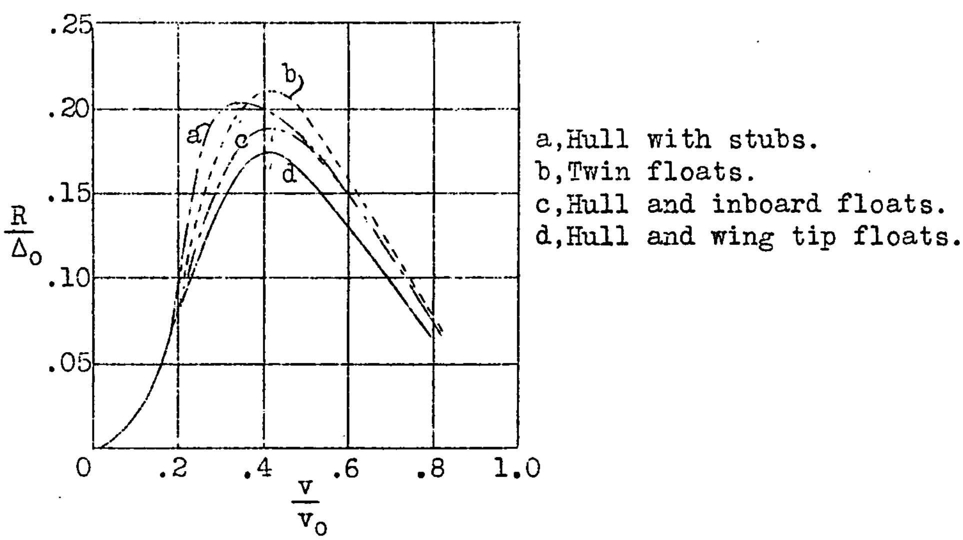


Fig.3 Comparitive resistance of various types of lateral stabilizers.

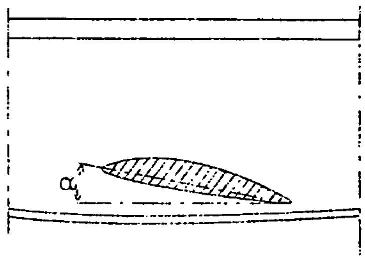
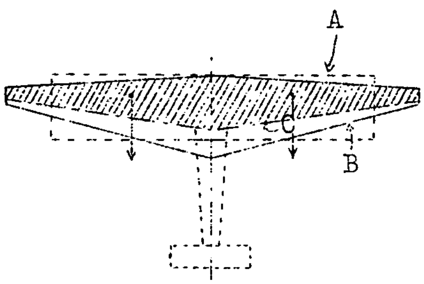


Fig.4 Large angle of attack of stub.



	A	B	C
Wing loading	p	p	1.5 p
Wind moment	M	M	2/3 M
Aspect ratio	1:5	1:8	1:12

Fig.5 Rolling moments for different wing shapes and wing loading.

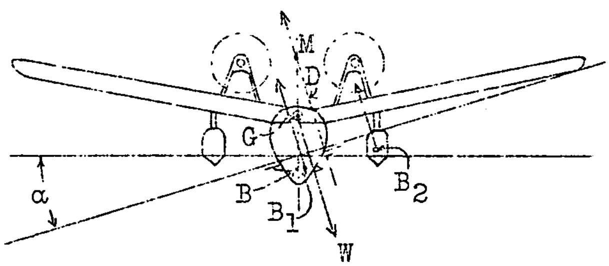


Fig.6 Large angle of inclination α with dihedral.

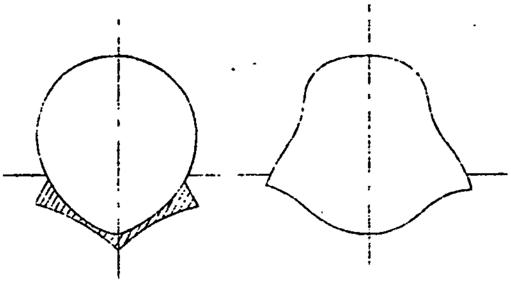


Fig.7 British hulls with well-rounded tops.